Digital Beamforming Synthetic Aperture Radar (DBSAR): Performance Analysis During the Eco-3D 2011 and Summer 2012 Flight Campaigns

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Introduction

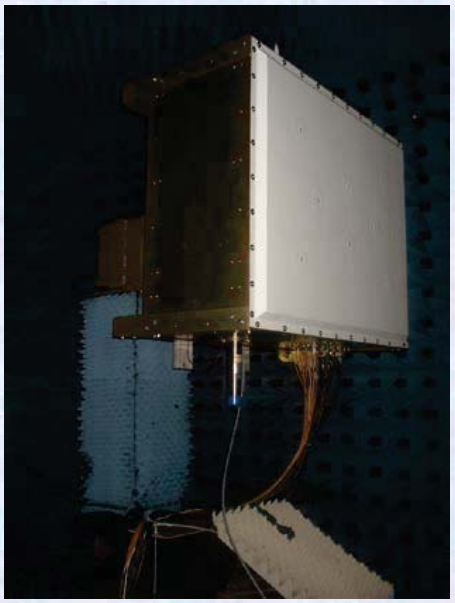
• The Digital Beamforming Synthetic Aperture radar (DBSAR) is a state-of-the-art airborne radar developed at NASA/Goddard for the implementation, and testing of digital beamforming techniques applicable to Earth and planetary sciences.

• The DBSAR measurements have been employed to study:
  • The estimation of vegetation biomass and structure - critical parameters in the study of the carbon cycle.
  • The measurement of geological features – to explore its applicability to planetary science by measuring planetary analogue targets.

• The instrument flew two test campaigns over the East coast of the United States in 2011, and 2012. During the campaigns the instrument operated in full polarimetric mode collecting data from vegetation and topography features.

Background

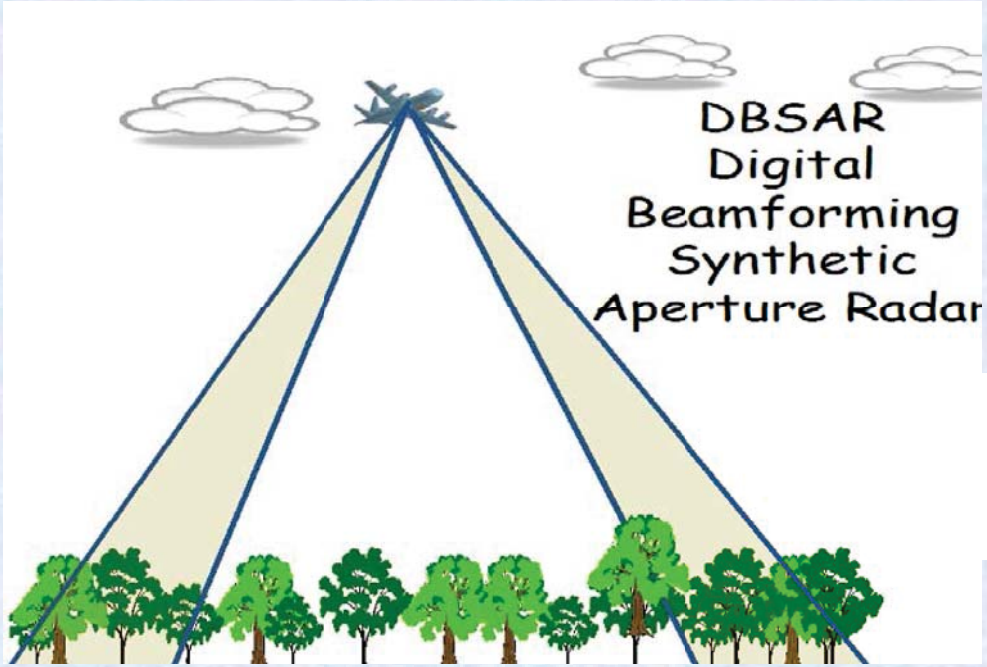
The DBSAR Instrument



- DBSAR is an L-band (1.26 GHz) radar

radar that employs advanced radar technology, and a customized data acquisition and real-time processor in order to enable multi-mode measurement techniques in a single radar platform.

- One of DBSAR's main features is its digital beamforming processing capability that enables the synthesis of multiple antenna beams simultaneously permitting the implementation of non-conventional imaging techniques.



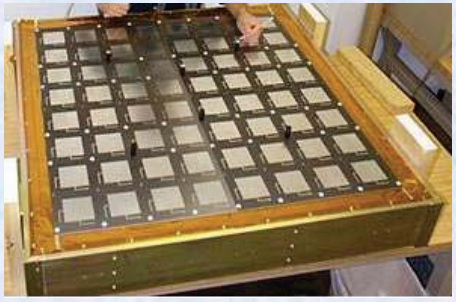
DBSAR enables high resolution Synthetic Aperture Radar (SAR) images over multiple beams.

Architecture

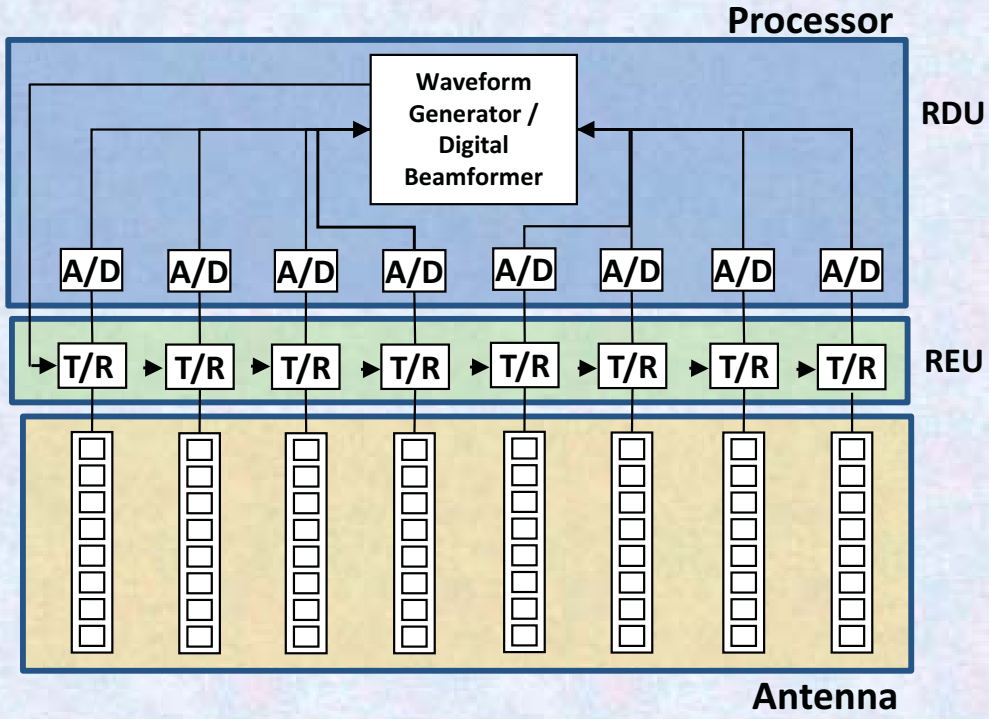
The DBSAR architecture consists of three main subsystems: the Radar Electronics Unit (REU), the Radar Digital Unit (RDU), and the phased array antenna.

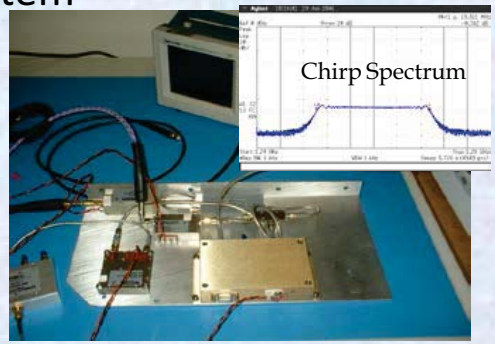
- 8 channels enable cross-track scanning at multiple polarizations (HH,VV,VH,HV)
- Transmit modules feature digital phase and amplitude control
- Digital beamforming on receive provides full beam control
- Phased array antenna has 64 active microstrip patch elements
- Customized, fully reconfigurable data acquisition and processor system

Radar Electronics Unit

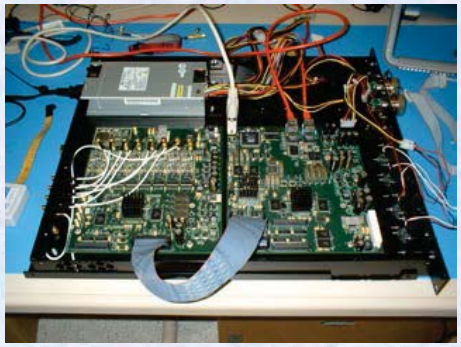


Phased Array Antenna





Waveform Generator



Data Processor

Instrument Characteristics

DBSAR system features include:

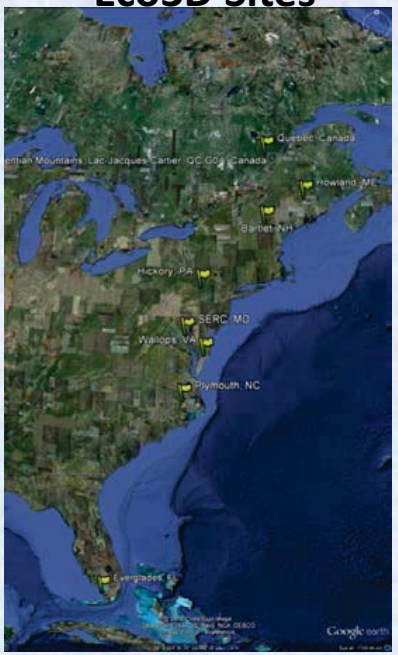
- Multimode operation: SAR, scatterometer, altimeter.
- One-dimensional scanning (across track in nominal configuration).
- Polarimetric operation (HH,VV,VH,HV).
- Real-time onboard processing.
- Adjustable transmitter illumination.
- Reconfigurable waveform generation.
- Noise source and closed loop calibration schemes.
- Real-time data monitoring through a customized graphical interface unit.

DBSAR Main Parameters	
Frequency	1.26 GHz (L-band)
Bandwidth	20 MHz
PRF	50 Hz to 10 kHz
Pulse Width	1 to 100 µs
Polarization	HH, VV, VH, HV
Slant Range Resolution	7.5 m
Max. Radiated Power	16 W
Beam Steering Range	> ±50 degrees
Antenna Type	Patch Array
Antenna Size	1.2 m x 1 m
Number of Patches	80
Number of Subarrays	8
Subarray Gain	12.5 dBi
Subarray 3-dB Beamwidth	106 degrees
Array Gain (nadir)	21.5 dBi
Array 3 dB Beamwidth (1-way)	15.6 Degrees (Cosine taper)
Array Side Lobes (1-way)	-23 dB (cosine taper)

The Eco 3D and Summer 2012 Science Flight Campaign

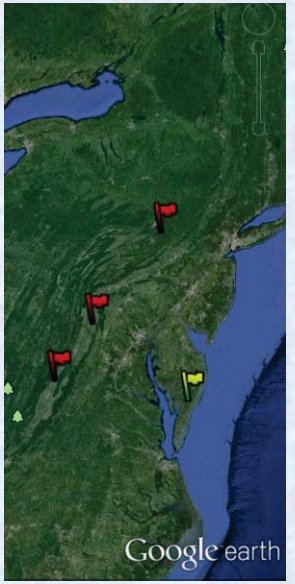
• The Eco-3D campign was conducted over areas of Maine, Quebec, New Hampshire, Pennsylvania, Florida, North Carolina, Maryland, and Virginia, collecting data across multiple forest types ranging from Boreal to tropical wetlands.

Eco3D Sites



•The Summer 2012 airborne campaign was over areas of the Delmarva peninsula on the east coast of the United States, and over the Appalachian mountain range in the states of Virginia, Maryland and Pennsylvania.

Summer 2012 Sites



Eco 3D Science Flight Campaign Sites

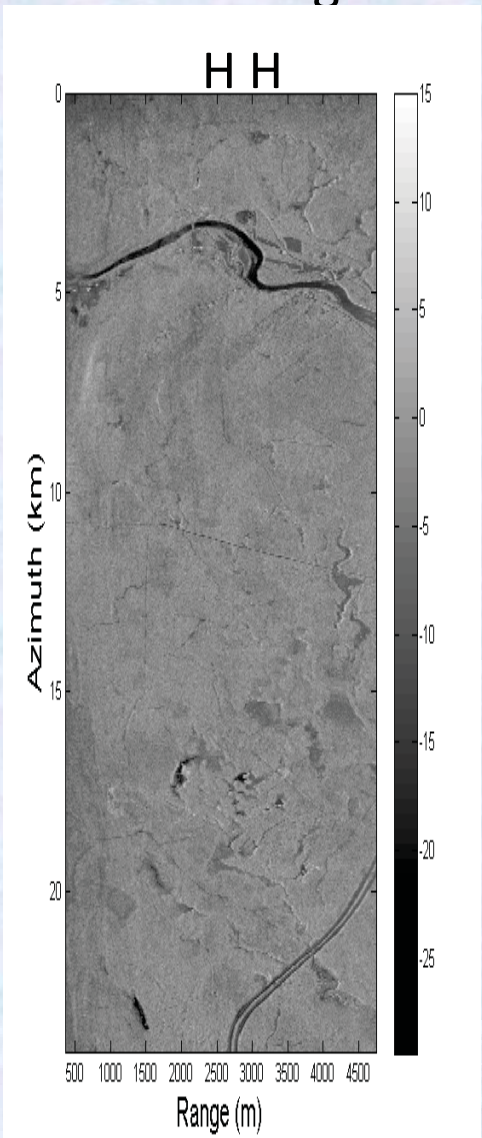
State	Name of Site	Type of Ecosystem
Maryland/ Virginia	Wallops Flight Facility/Smithsonian Ecological Research Center	Mixed Hardwood/ Coastal Plain Oak-Conifer/ bare sandy surfaces
Pennsylvania	Hickory Run	Mixed Hardwood forests, boulder field
Maine	Howland and Penobscot Forests	Boreal/ Northern Hardwood transition
New Hampshire	Bartlett and Hubbard Brook Forests	Boreal/Northern Hardwood transition, mountainous topography
Quebec	Parc des Laurentides/ Parc de la Jacques-Cartier	Boreal
Florida	Everglades National Park	Mangrove forest/ sawgrass marsh/ hardwood hammock
North Carolina	Parker Track	Pine Plantation

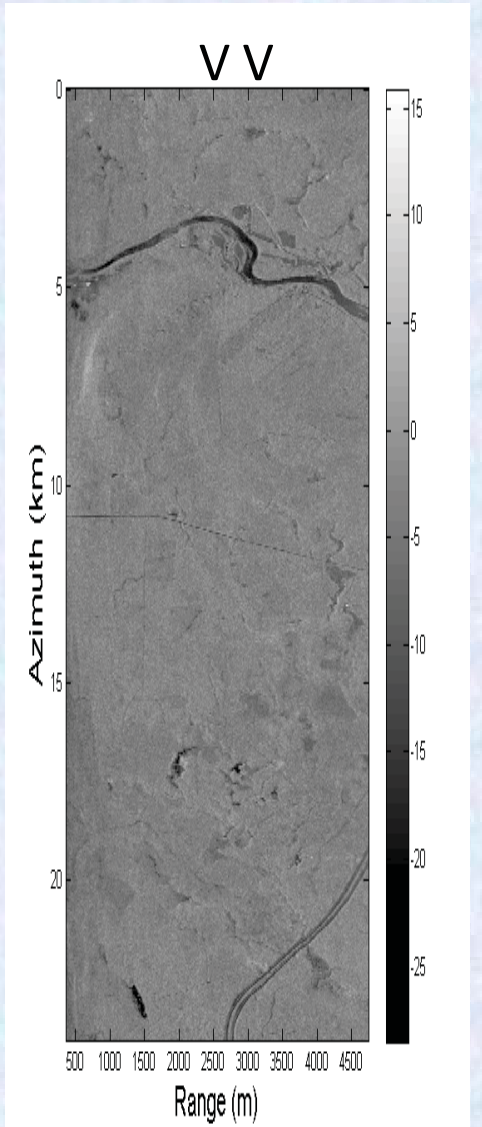
Summer 2012 Campaign Sites

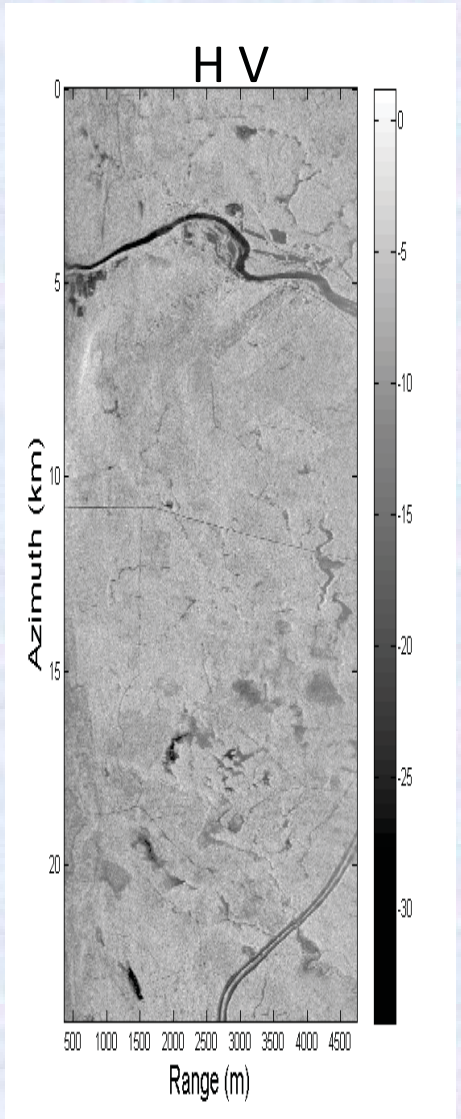
Name	Size (m)	Lat	Lon	Notes
Hickory Run, PA	550x120	41°02’10”N	75°41’02”W	rounded boulders
River of Rocks, PA	1600x65	40°38’14'' N	75°58’15'' W	Hawk Mountain/Allentown, quartzite
Blue Rocks, PA	805x 200-600	40°36’ N	75°55’ W	3 mi. NE Hamburg PA, quartzite
Devil's Racecourse, PA	1280x30	40°26’28'' N	76°44’13'' W	too narrow? Harrisburg, Stoney Mt.
Quirauk Mountain, MD	550x35	39°40’15'' N	77°31’18'' W	Thurmont, also called Devil's Racecourse
South Mountain/Wolfe Rd, MD	500x80	39°34’30'' N	77°35’53'' W	just west of Frederick
Waonaze Peak north, VA	800x25-72	38°48’17'' N	78°30’45'' W	east of I-81/Edinsburg
Waonaze Peak south, VA	580x144	38°47’50'' N	78°30’8'' W	multiple blockslides over 900 m, Powell Mt. trail
Massanutten Mountain, VA	1500x30-150	38°37’50'' N	78°36’55'' W	east of I-81, west of Luray
Shenandoah 1, VA	5000 x 1000	38°20’11'' N	78°38’31'' W	lots of small fields over big area
Shenandoah 2, VA	5000 x 5000	38°17’35'' N	78°40’55'' W	lots of small fields over big area, closer to road
Wallops, VA / Snow Hill, MD	66000 x 45000	38° 6'41"N	75°29‘54"W	Corner Reflectors / hardwood, conifers

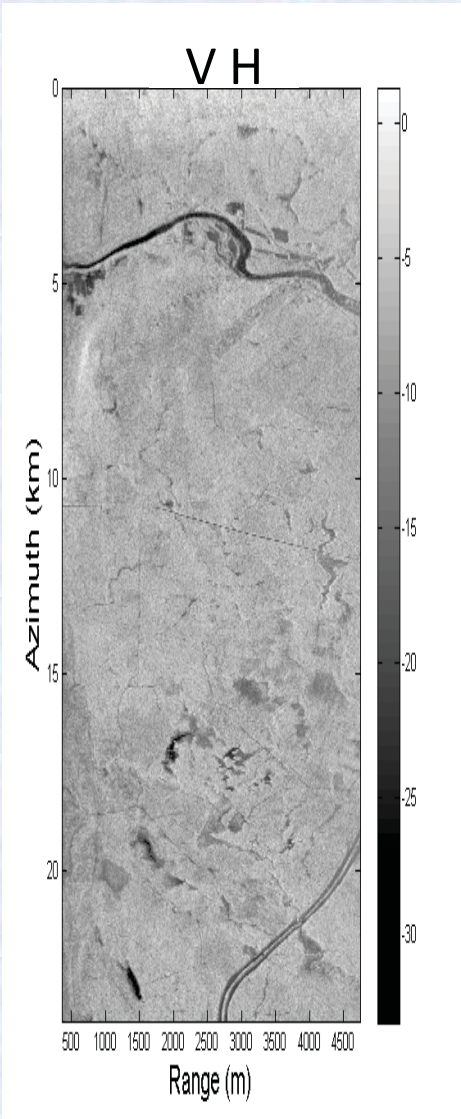
DBSAR's Polarimetric Measurements

DBSAR Polarimetric measurements are sensitive to the shape, orientation and pdielectric properties of scatterers and allows the identification and separation of the scattering mechanisms.



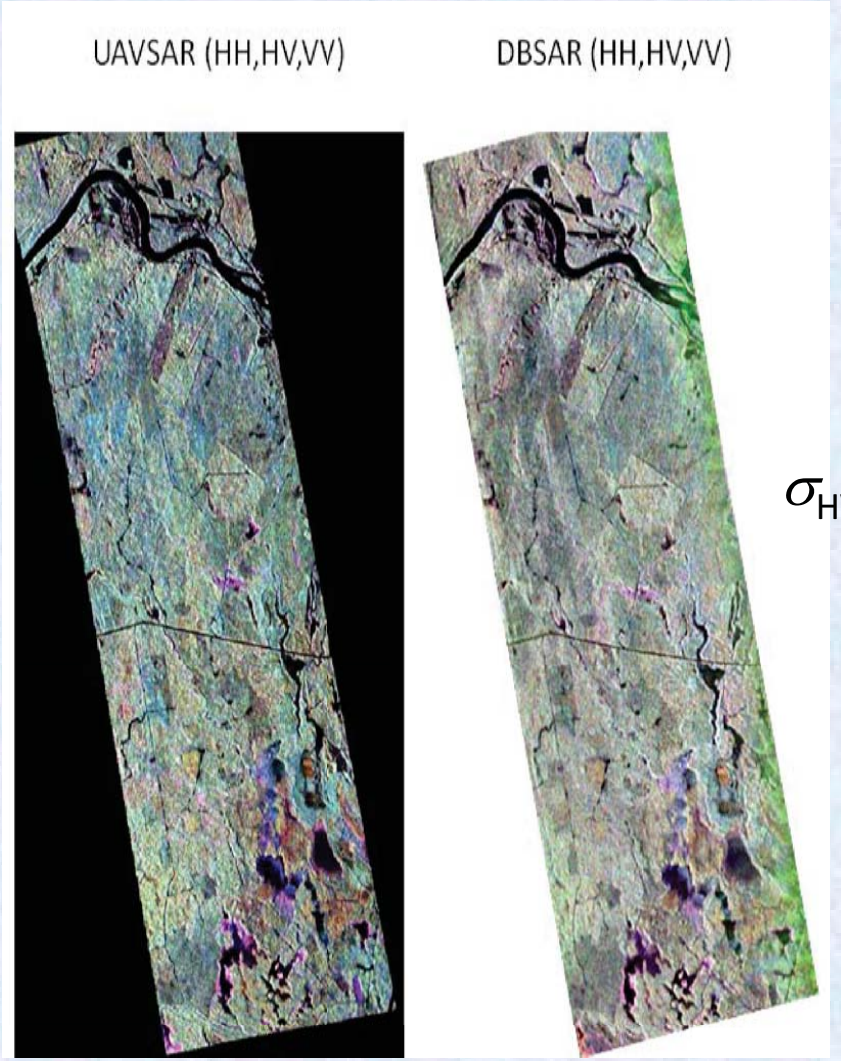




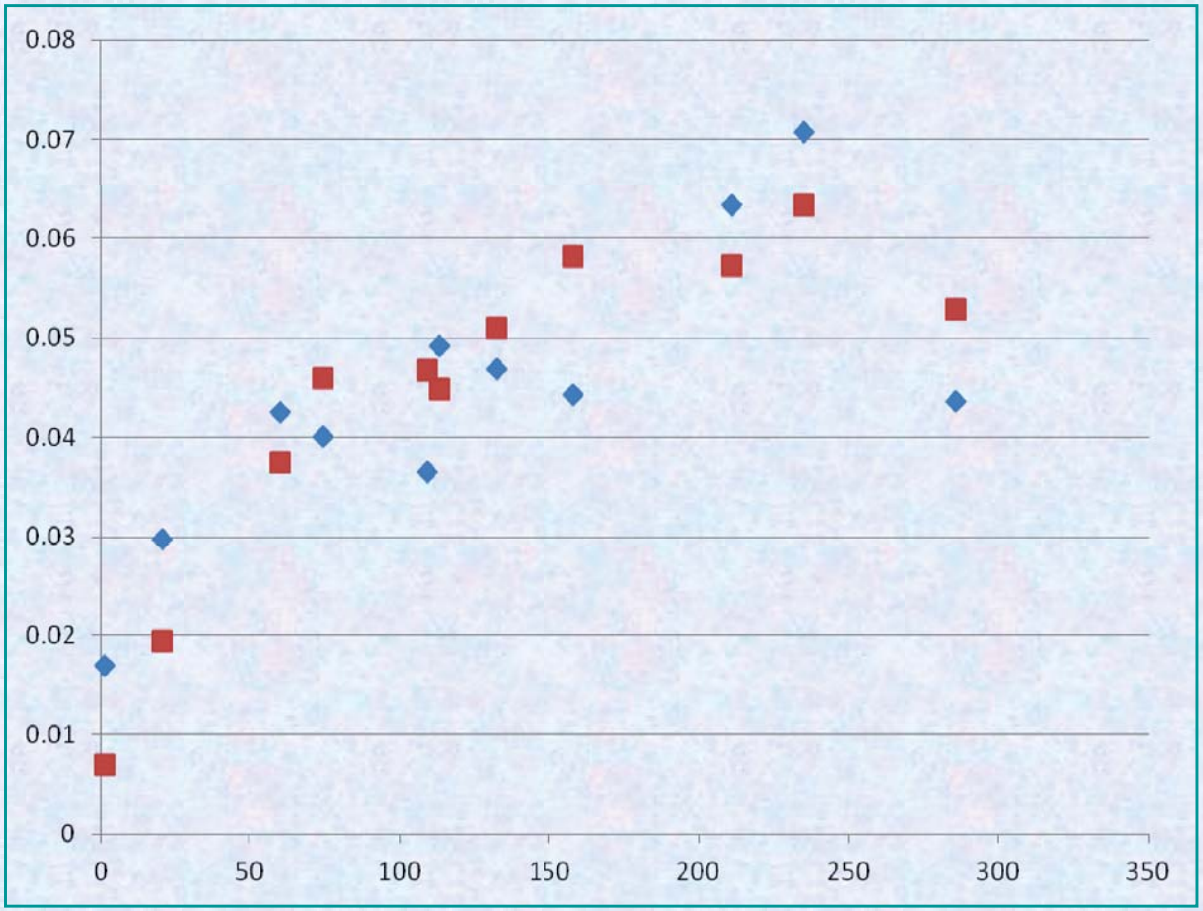


DBSAR's Biomass Estimtates

Comparison between DBSAR and UAVSAR polarimetric backscatter using RGB composite (left) and biomass estimates (right). The biomass data was obtained from 11 1-ha (50m x 200m) plots within the imaged area.

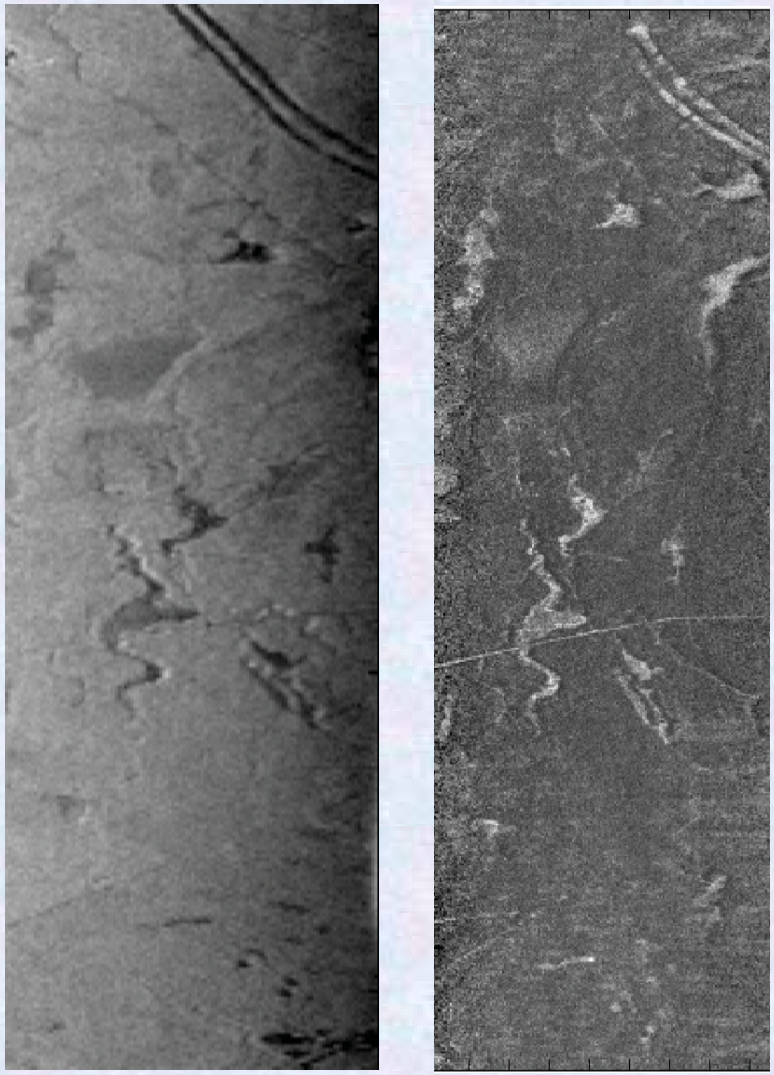


DBSAR HV (◆), UAVSAR HV(■)



DBSAR's InSAR Measurements

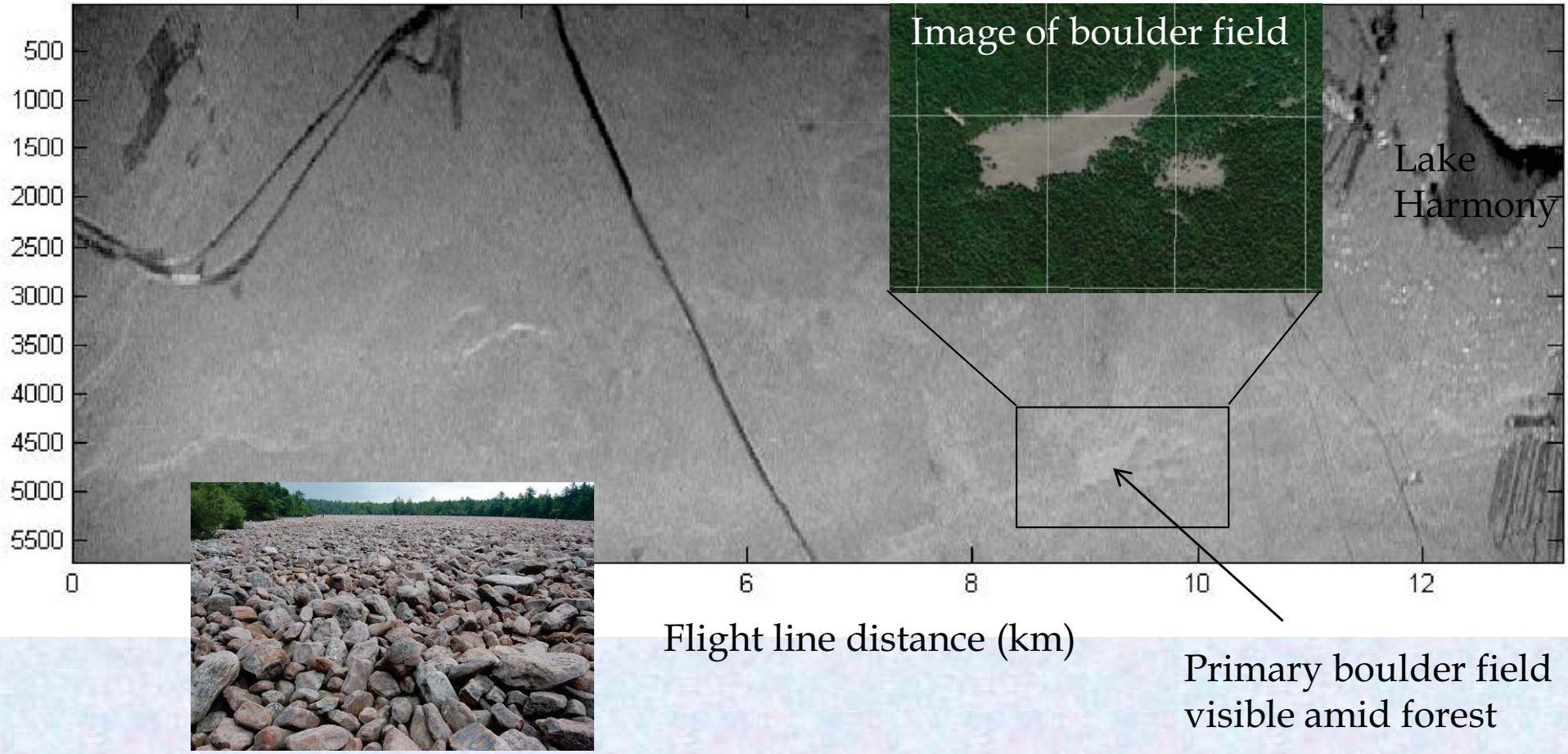
DBSAR's digital beamforming enables the implementation of "single-pass" Interferometric techniques (InSAR). InSAR measurements are sensitive to the spatial variability of vertical structure parameters and can provide quantitative information on the layered structure of the vegetation, such as the depth and density.



DBSAR intensity (Left) and interferometric (Right) images acquired over Howland, ME, on Sept 16, 2011

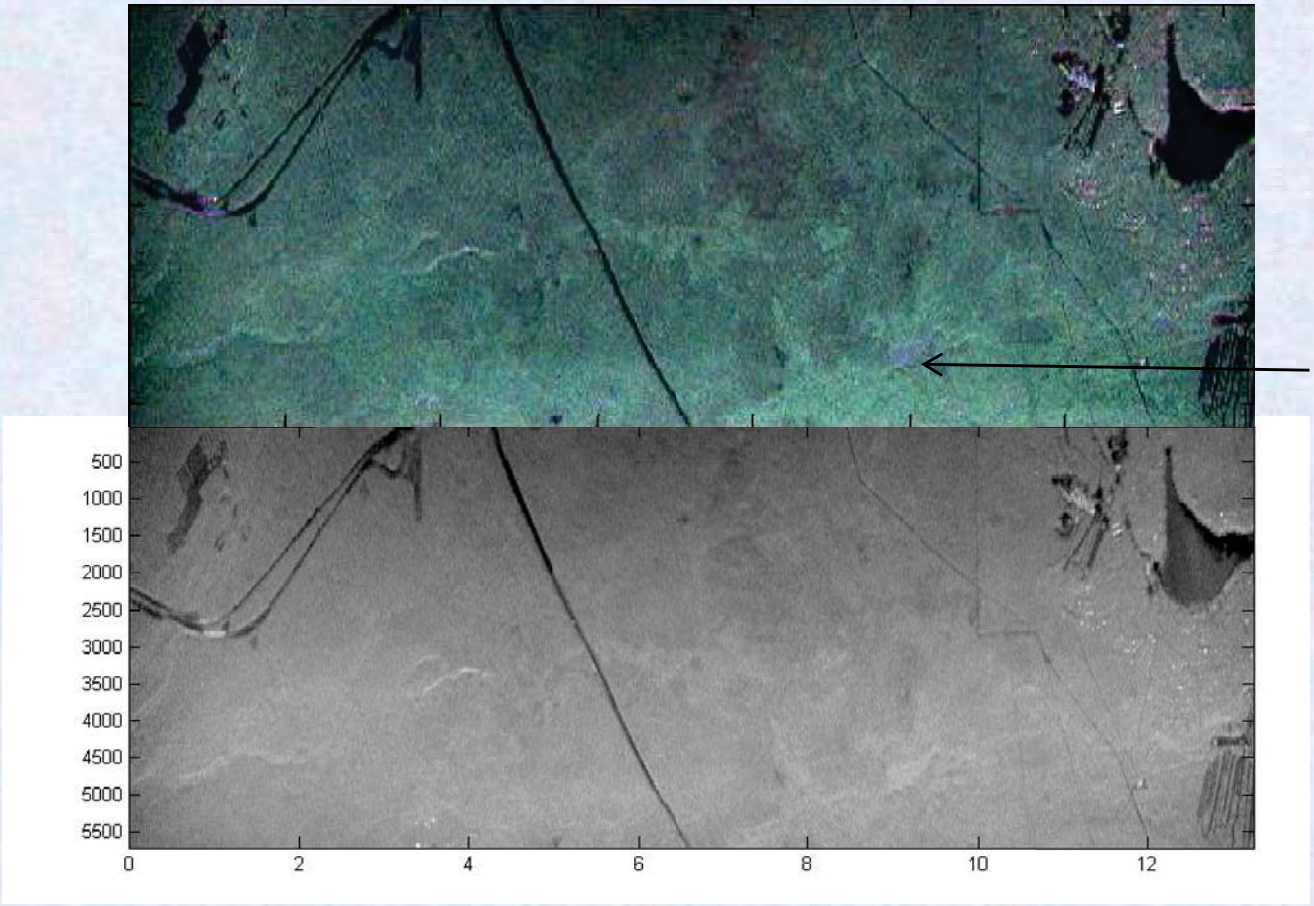
DBSAR's Applied to Geology

- Example of HV polarization image data for Hickory Run:



DBSAR's Applied to Geology

- **RGB image of Hickory run using HH, HV, VV data.**

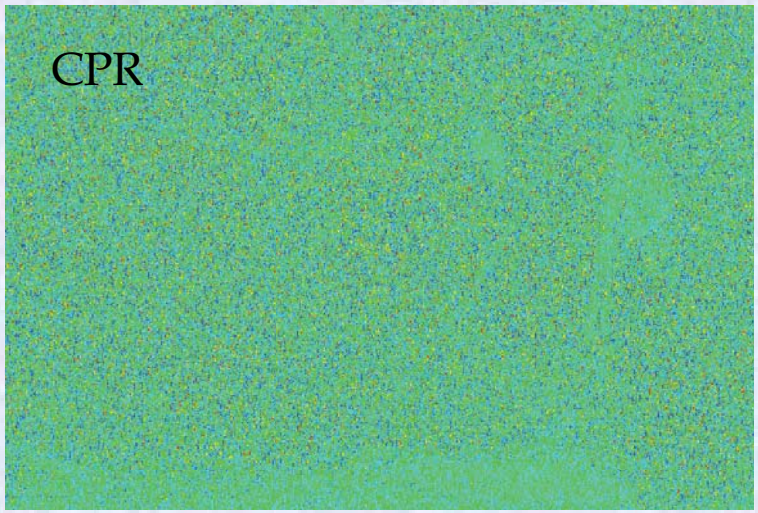


Primary boulder field has different polarization behavior from surrounding forest and man-made structures.

DBSAR's Applied to Geology

- Software has been produced to use the DBSAR data to create polarimetry products commonly used in planetary science, and has been tested on 2011 Hickory Run data.
  - E.g. Stokes polarization vector and daughter products

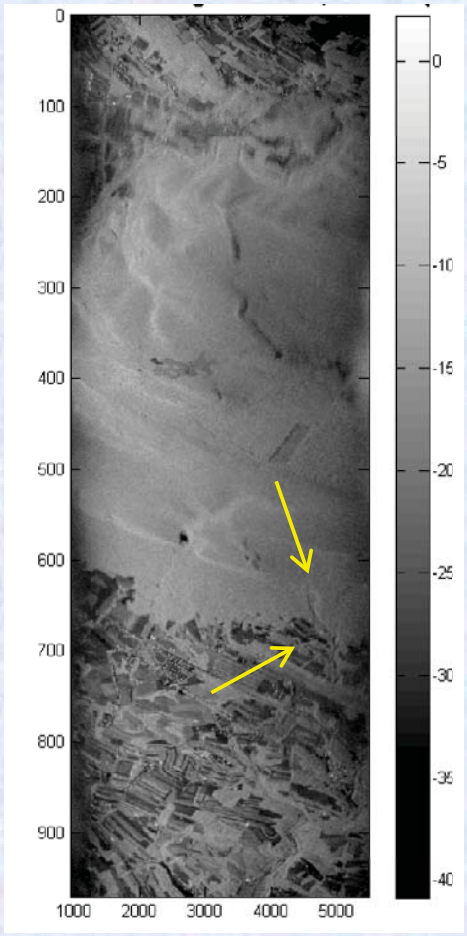
$$S = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix} = \begin{bmatrix} \langle |E_H|^2 \rangle + \langle |E_V|^2 \rangle \\ \langle |E_H|^2 \rangle - \langle |E_V|^2 \rangle \\ 2\mathrm{Re}\langle E_H E_V^* \rangle \\ -2\mathrm{Im}\langle E_H E_V^* \rangle \end{bmatrix} \qquad CPR = \frac{S_1 - S_4}{S_1 + S_4}$$

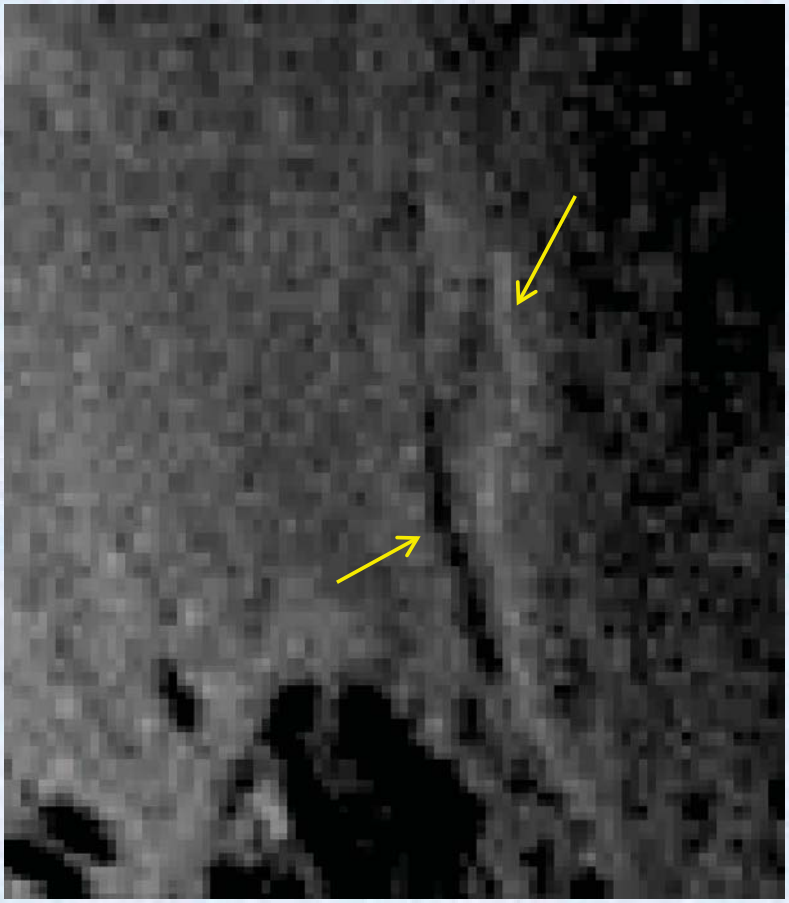


DBSAR's Applied to Geology

– New polarimetry data were acquired over VA and PA blockfields at multiple incidence angle and look angles, to explore the scattering behavior of the rock fields.

Preliminary (low-res quick-look) DBSAR data of Blue Rocks and Albany PA with different viewing geometries and image scales.





Blue Rocks

Conclusion

• This work seeks to evaluate DBSAR's polarimetric and interferometric digital beamforming techniques for the estimation of science parameters and the quantification of three-dimensional scattering mechanism.

• DBSAR participated in the Eco-3D and the Summer 2012 flight campaigns to measure vegetation biomass and structure and to explore its applicability to planetary science by measuring planetary analogue targets.

•During the campaign DBSAR operated in polarimetric and interferometric SAR modes using several beamfomring techniques. The polarimetric capability is a new system upgrade and was demonstrated for the first time during Eco3D.

• Analysis of the DBSAR Eco3D and summer 2012 flight data to measure above measure vegetation and geological features has shown a successful digital beamforming polarimetric operation the during the campaigns.